IMOS Integrated Marine Observing System

'Continuity is critical'

IMOS
Decadal Strategy
2011-20

Australian Government
Department of Innovation Industry, Science and Research

IMOS is supported by the Australian Government through the National Collaborative Research Infrastructure Strategy and the Super Science Initiative. It is led by the University of Tasmania on behalf of the Australian marine & climate science community.

UTAS

Executive Summary

This document sets out the strategic priorities for sustaining Australia's Integrated Marine Observing System (IMOS) long-term. Its fundamental premise is that Australia now has the research infrastructure capability to deliver critical information about ocean processes and marine systems on an ongoing basis if there is will to continue investing. This has led us to title the Strategy, '*Continuity is critical*'.

The Decadal Strategy builds on the IMOS Five Year Strategy (2009-13)[1]. It draws on five years of comprehensive Annual Business Planning and Progress Reporting provided to the Department of Innovation Industry Science and Research (DIISR)[2]. Appropriately, it relies very heavily on the IMOS Science and Implementation Plans developed by the Australian marine and climate science community over the last two and a half years, all components of which have now been internationally peer-reviewed[3].

In total this represents in excess of 2,000 pages of documentation setting out the rationale for a national scale integrated marine observing system, assessing the state of our current understanding about Australia's oceans, identifying gaps, establishing observational priorities, developing implementation plans, and reporting on progress which, by all objective measures, has been excellent to date. This Decadal Strategy is, therefore, as brief and to the point as possible.

IMOS is introduced. The need for a Decadal Strategy is articulated. A suite of strategic priorities is outlined. And various forward planning scenarios are considered.

Integrated marine observing is a necessarily complex endeavour, and the strategy for sustaining IMOS across decadal timescales needs to be multi-dimensional – hence a 'suite' of strategic priorities. These are not standalone priorities, and by design they have many interdependencies and overlapping elements. The suite of priorities for the next decade is set out below. The numbering in no way denotes ranking or hierarchy.

1. Ensuring that the in-situ ocean observing system continues to be a vital component of Australia's National Research Infrastructure
2. Continuing to undertake national-level science and implementation planning that is globally and regionally integrated, to guide ongoing development of the observing system
3. Continuing to build institutional strengths into national capability, by implementing the principles of national collaborative research infrastructure investment
4. In the context of Australia's e-Research agenda, leveraging IMOS electronic marine information infrastructure to help create a culture that enables all Australian marine and ocean climate data to be discoverable, accessible, and interoperable

[1] http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/EIF/IMOS_Five_Year_Strategy_final_1509.pdf
[2] http://imos.org.au/plansreports.html
[3] http://imos.org.au/plans.html

5. Ensuring IMOS data is taken up and used for marine and climate research that addresses national priorities in order to benefit Australian society, by implementing a comprehensive plan of engagement with all relevant components of the National Innovation System
6. Catalysing a national scale engagement between the marine observing system and marine modelling communities, to help improve the relevance and applicability of both
7. Engaging with terrestrial, freshwater, geological, cryospheric, and atmospheric research communities to promote systems-based research, particularly in the coastal zone
8. Engaging with international ocean observing programs in our region, to ensure that Australia takes full advantage of collaborative opportunities in the Southern Hemisphere
9. Improving efficiency through vigorous collaboration, data capture and reuse, and ongoing technical innovation
10. Engaging with operational agencies and other partners responsible for delivering marine environmental information and ocean products and services, to ensure that IMOS co-evolves with related operational observing systems.

Three forward planning scenarios are considered. Maintain and sustain, to provide continuity at the current scale of operation. Evolutionary growth, to fill identified gaps. In the bluewater, major gaps exist in the deep ocean, the high latitudes, the tropics, and the major boundary currents. In the coastal oceans there remain significant gaps across Northern Australia, and in scientifically important places in South Eastern Australia. And strategic enhancement, to enable IMOS to move into new areas of national priority - in sea ice, in national coastal observing, and in sustained ecological observing.

This Decadal Strategy will inform, and be informed by, DIISR's processes for establishing a Strategic Framework for Research Infrastructure Investment and the next Strategic Roadmap for Australian Research Infrastructure. The outcome of these processes will determine which combinations of the forward planning scenarios, or variants thereof, actually come into being.

The Decadal Strategy will be developed over coming years in the spirit of national collaboration that underpins the existence of IMOS.

April, 2011

Introduction

IMOS was established in 2007 under the National Collaborative Research Infrastructure Strategy (NCRIS), with initial funding of $50M and co-investment of ~$60M from partners. It has successfully deployed a range of observing equipment in the oceans around Australia, making all of the data freely and openly available through the IMOS Ocean Portal for the benefit of Australian marine and climate science as a whole. IMOS became bigger and better with the injection of an additional $52M from the Education Investment Fund (EIF) in 2009, and up to a further ~$60M of co-investment. This has enabled IMOS to deliver a greater range of ocean data, to more stakeholders, for longer.

The IMOS community has demonstrated that Australia has the capability and capacity to deliver national collaborative research infrastructure in the form of an ocean observing system. Multiple pathways to uptake and use have been established – through research education and training, research projects and programs, analyses and products, and modelling and forecasting systems.

IMOS is designed to be an integrated, national system, with open-ocean and coastal components, and covering physical, chemical and biological variables. IMOS Facilities, operated by nine different institutions within the National Innovation System, are funded to deploy equipment and deliver data streams for use by the entire Australian marine and climate science community and its international collaborators**.** The IMOS Ocean Portal allows marine and climate scientists and other users to discover and explore data streams coming from all Facilities, some in near-real time, and all as delayed-mode, quality-controlled data. These data streams, long time-series that are 'under construction', represent the actual research infrastructure being created and developed by IMOS.

IMOS observations are guided by science planning undertaken collaboratively across the Australian marine and climate science community. This is a large, diverse, dispersed community, and it has made sense to develop the science planning through a series of integrated Nodes – a 'Bluewater and Climate' Node focused on the open ocean, and five 'Regional Coastal Nodes' covering the continental shelf and coastal seas of Western Australia, Queensland, New South Wales, Southern Australia and Tasmania. Leaders of the Nodes come together to form a national steering committee that oversees the whole process, and Node science plans are subjected to international peer review on a rolling basis to ensure the planned science is world-class.

Five major research themes unify the IMOS Node science plans and related observations i.e. (1) Multi-decadal ocean change, (2) Climate variability and weather extremes, (3) Major boundary currents and inter-basin flows, (4) Continental shelf processes, and (5) Ecosystem responses.

The IMOS Facilities enable multi-platform approaches to be taken in addressing these major research themes within the Nodes. This also drives efficiency through the IMOS Facilities having multiple purpose and use, and being broadly utilised across the whole community.

In summary, NCRIS presented both an opportunity and a challenge to Australian science. Through IMOS, the marine and climate science community has clearly risen to this challenge, and seized this wonderful opportunity by changing the way in which it works together.

The need for a Decadal Strategy

The societal need for ocean observations derives from:

- The opportunities presented by Australia's huge ocean territory
- The economic benefit we derive from the ocean through safe and efficient marine industries
- The role of the ocean in Australia's climate and weather
- The concentration of population in Australia's coastal cities and communities, and
- The globally significant marine biodiversity that lives from Australia's high tropics to Antarctica.

These factors combine to make sustained observing of the ocean a matter of national significance for current and future generations of Australians.

It is implausible to think that Australia would not have research vessels in which to go to sea, or marine laboratories in which to analyse samples. Recent re-investments in Australian vessel and laboratory infrastructure testify to this fact. These are investments with 25 to 40 year economic lifetimes. It should be equally implausible that Australia would not have the capacity to make in-situ observations of its ocean territory, particularly as a country that does not have its own satellite remote sensing capability. And that we would not contemplate investment in in-situ ocean observing infrastructure across decadal timescales.

This need was well-articulated in the NCRIS Evaluation Report[4] (emphasis added):

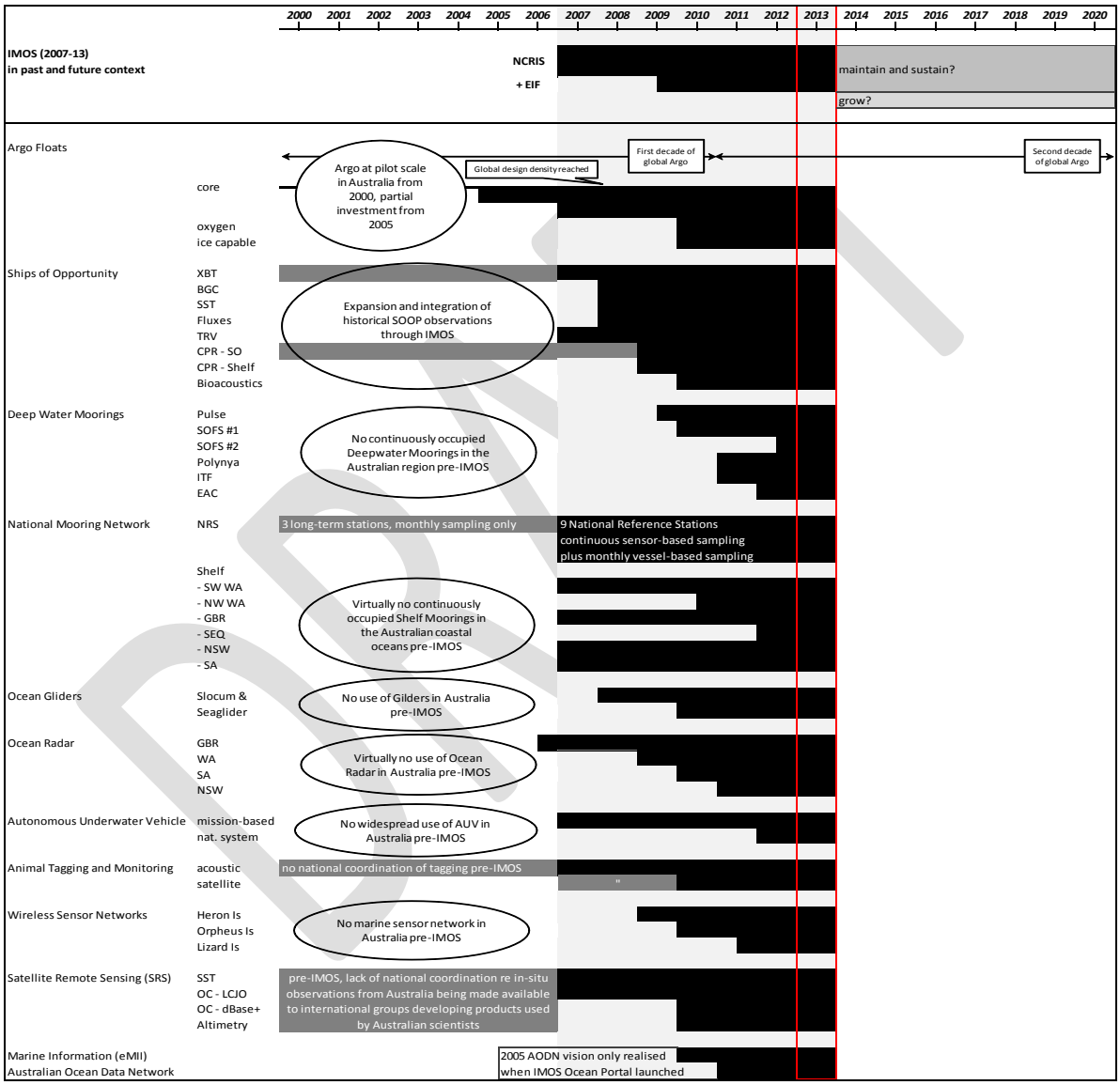
> *This definition of infrastructure, and the recognition of **data and information as infrastructure**, is central for some capabilities. The observation-based capabilities such as IMOS...are providing continuous data streams of critical information **about processes that operate on long time scales**, such as ocean-climate dynamics... and that lead to understanding of climate change or natural hazards. They provide timely access to quality assured observational data that can be used by the Australian research community. Together with the data, these facilities are providing the tools for effective use of these data streams, allowing them to be used by a wider community of researchers including for the development of applied user products. **Ongoing support for these data streams is essential to maintain the value of the original investment.** New research outcomes will be driven by the improvements in temporal and spatial resolution of the record as well as by the increasing interactions between the users of the data streams. This is not a static process. The dynamic nature of the phenomena being observed means that **it is an ongoing observation task**. Interruptions in the data streams significantly reduce their value as infrastructure, so **continuity is critical** for as long as the impacts of the phenomena are considered to be important. This view of infrastructure has also created new opportunities for researchers. One of the things achieved under the NCRIS program is the introduction of technologies and data streams not otherwise available to individual researchers or even institutions. **This will increasingly create the flexibility to use these facilities as new research challenges emerge in areas requiring multi-disciplinary approaches.***

In summary, the key point is that 'continuity is critical'.

[4] NCRIS Evaluation Report, June 2010 – p23

The cost of in-situ ocean observing is not trivial. However the benefits are potentially enormous. One study in 2006 estimated a benefit cost ratio of 22.6 to 1 on Australian Government investment in ocean observing[5]. Furthermore, Australia is in a unique position to achieve very substantial international leverage on its investment in ocean observing. The Southern Hemisphere is globally important, but comparatively under-observed, and Australia in seen by Northern Hemisphere powers as a strong partner in the global ocean observing enterprise.

The diagram below illustrates how ocean observing in Australia has been built up through the establishment of IMOS.



The impetus for this Decadal Strategy comes from the potential to continue delivering a 'step change' in critical information about ocean processes and marine systems if this effort is sustained.

[5] http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/documents/external_reports/Economics_of_Australia_a_Sustained_Ocean_Observation_System_1_.pdf

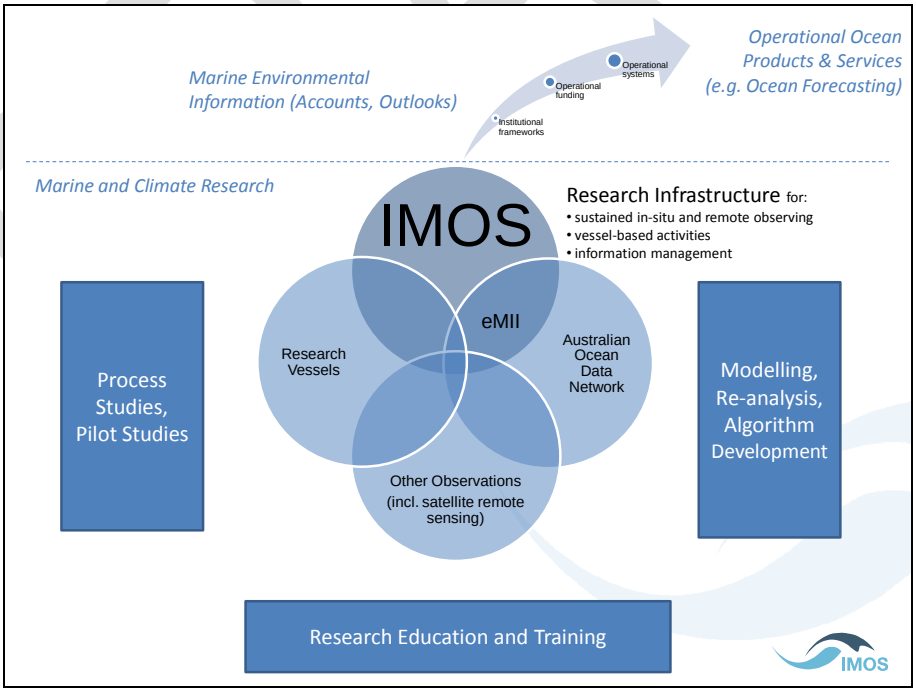
Ten Strategic Priorities for the next Decade

1. Ensuring that the in-situ ocean observing system continues to be a vital component of Australia's National Research Infrastructure

The 2006 NCRIS Strategic Roadmap[6] identified an Integrated Marine Observing System as one of sixteen national priority capability areas, and laid the platform for establishing IMOS. The current National Innovation Agenda[7], includes 'marine and climate science' as one of three 'super science' priority areas, and provided the second stage of investment in IMOS in mid 2009, along with re-investment in blue water research vessel capability and significant investment in marine laboratories in support of region-specific collaborations. It is anticipated that the new Strategic Roadmap for Australian Research Infrastructure being developed during 2011 will continue to have integrated marine observing as a priority capability area, and the initial Discussion Paper[8] gives some indication that this will be the case.

IMOS is positioned as the in-situ[9] component ocean observing system, distinguishing it from the research vessel and satellite components. It has a 'data centric' (rather than 'bricks and mortar') perspective on research infrastructure, which manifests through the discoverability and accessibility of all its data via an 'Ocean Portal' (http://imos.aodn.org.au/webportal/). This perspective received strong endorsement in the NCRIS Evaluation Report (see page 4) and has enabled IMOS to both benefit from and contribute to Australia's national e-Research agenda, including taking a lead role in establishing a broader Australian Ocean Data Network (AODN).

The position of IMOS within Australian marine and climate science can be illustrated as follows:



[6] http://ncris.innovation.gov.au/Documents/2006_Roadmap.pdf
[7] http://www.innovation.gov.au/Innovation/Policy/Documents/PoweringIdeas.pdf
[8] http://www.innovation.gov.au/Science/ResearchInfrastructure/Documents/2011_Roadmap_Discussion_Paper.pdf
[9] This is consistent with positioning of the Global Ocean Observing System (GOOS), noting that some aspects of IMOS stretch the definition of 'in-situ'.

IMOS will seek to ensure that the in-situ ocean observing system continues to be a vital component of Australia's National Research Infrastructure by:

a) Maintaining a strong track record in successful deployment and recovery of marine observing platforms and sensors.

b) Partnering with research vessel operators in deployment and recovery activities, and in instrumenting research vessels as ships of opportunity to create a 'virtual fleet'.

c) Partnering with international satellite remote sensing programs (e.g. at NASA, ESA) to ensure that Australian in-situ observations are made available to calibrate sensors and validate product performance in our region.

d) Making all IMOS data discoverable and accessible for free, and adding value to this investment by leveraging the information infrastructure into a broader Australian Ocean Data Network that contributes to the Australian Research Data Commons.

e) Establishing multiple pathways to uptake and use of data streams, through research education and training, research projects and programs, analyses and products, and modelling and forecasting systems (including development of Australian regional algorithms for remote sensing products where this is justified).

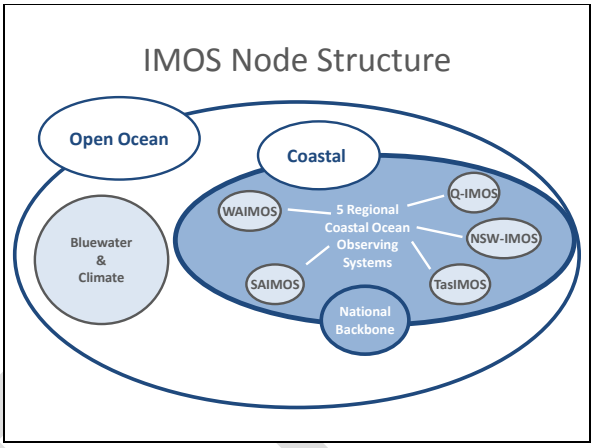
f) Partnering with operational agencies and others responsible for delivering marine environmental information and ocean products and services.

g) Partnering with terrestrial, freshwater, geological, cryospheric, and atmospheric research communities to promote systems-based research.

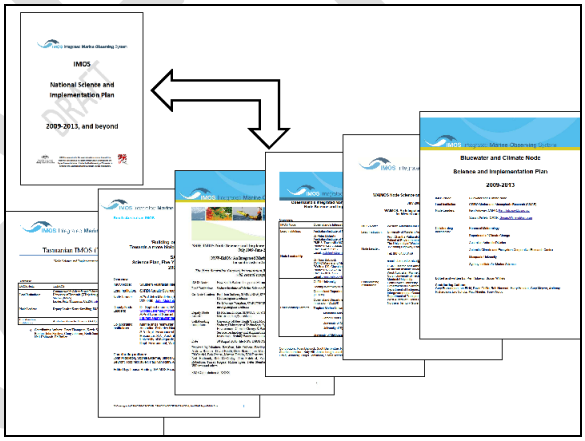
2. Continuing to undertake national-level science and implementation planning that is globally and regionally integrated, to guide ongoing development of the observing system

IMOS has been established in a 'matrix' of Nodes and Facilities. Nodes provide the scientific rationale for the observing system, and Facilities own and operate the required platforms and sensors, and deliver the required data streams for uptake and use through the Node communities.

The Node structure has been designed according to GOOS principles, with linked open-ocean and coastal components. The open-ocean component (Bluewater and Climate Node) is firmly embedded in relevant international programs, and the coastal component comprises a national backbone and a series of regional nodes - Western Australia (WAIMOS), Queensland (Q-IMOS), New South Wales (NSW-IMOS), Southern Australia (SAIMOS) and Tasmania (TasIMOS).



Science and implementation planning within IMOS has been undertaken at Node level. The quality of science planning improved during 2009-10, through focused effort by the Node communities and international peer review of all plans. Node Leaders have worked together very effectively as a national Steering Committee to oversee this process. By early 2011, the IMOS science planning processes had matured to a point at which there was community support to move to a National Science and Implementation Plan with six node chapters[10].



This step enables IMOS to build on the strengths of its Node planning, including regional relevance, while also enabling better integration of the open-ocean and coastal components, a more effective national backbone, and less risk of fragmentation across coastal regions.

IMOS will continue to guide the observing system through science and implementation planning by:

a) Ongoing development of community-driven National and Node plans, with particular emphasis on opportunities in national coastal observing, greater synergy between observations and models, and sustained ecological observing. Node plans should be recognisable applications of the National plan in regional settings, using regional knowledge and expertise.

b) Ongoing international and external peer review.

c) Strengthening of Node governance to maintain community confidence in IMOS processes.

d) Strengthening engagement with stakeholders who fund and use research which relies on marine observations, to maximise potential for IMOS to have impact, and to attract co-investment.

[10] http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/documents/IMOS/Plans___Reports/IMOS_National_Science_and_Implementation_Plan_DRAFT_080411.pdf

3. Continuing to build institutional strengths into national capability, by implementing the principles of national collaborative research infrastructure investment

The IMOS Facility structure has been successful in leveraging the strengths of different research institutions across Australia to build capability in marine observing through a suite of 'national facilities' with critical mass, and a focus on making data available for use by the entire marine and climate science community.

Facilities are the funded dimension within the IMOS 'matrix'. Implementation has been managed through the University of Tasmania (UTAS), as Lead Institution, assisted by an Advisory Board comprised of an Independent Chair and members nominated by the marine community for their abilities to guide the program. UTAS has signed head contracts with DIISR and then sub-contracted with various Operating Institutions to own and operate the Facilities and Sub-Facilities. The Operating Institutions also provide a substantial proportion (~60%) of the co-investment required to operate IMOS at its current scale.

The NCRIS Evaluation Report[11] looked at different governance models i.e. unincorporated joint venture, incorporated entity, and lead institution with agreed access arrangements (the IMOS model). The evaluation did not uncover any evidence that any particular governance model was more or less appropriate for the program, and there appears to be no compelling reason to consider changing the IMOS governance model.

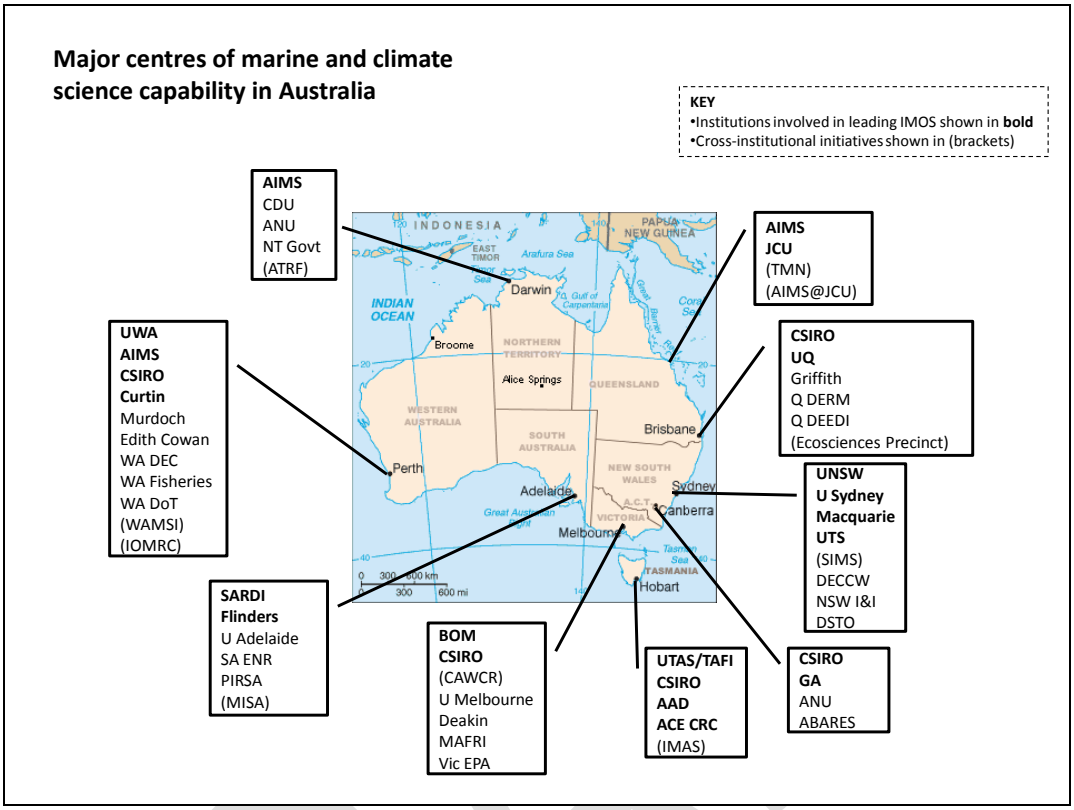
Performance of Facility Operators is managed via contractual milestones updated through an Annual Business Planning process. As IMOS has matured, the focus of milestones has shifted from being primarily about capability development and deployment, to a much clearer focus on availability of data streams. Under EIF, milestones are set on a quarterly basis which has added additional rigour. Overall, the performance of IMOS Facilities and Sub-Facilities in building capability, deploying and recovering equipment, and delivering data streams for uptake and use by the community has been very good. Some issues remain around availability of data streams in usable formats, and these are receiving dedicated attention. It will be important for IMOS to continuously evaluate the utility of its data streams, and be prepared to disinvest in Facilities or Sub-Facilities if greater value can be delivered to the marine and climate science community by making alternative investments.

The capacity of a Lead Institution and Operating Institutions to sustain a national partnership model over decadal timescales does need to be considered. Risks include discontinuity of national research infrastructure funding, failure of partners to agree on forward directions, and non-performance of particular institutions jeopardising the partnership. An alternative would be to institutionalise the IMOS Facility investments on the understanding that they continue to operate as national facilities. However this would not necessarily quarantine the investments from future cuts, and could diminish the considerable strengths of IMOS national-level planning and multi-institutional delivery.

Two factors strongly mitigate the risks associated with pursuing a long-term national partnership model. Firstly, the value of the observing system as implemented through IMOS will increase over time, providing all partners with a clear business imperative for ongoing engagement and investment. Secondly, Australia's National Innovation Agenda is providing strong incentives for the creation of multi-institutional partnerships, and this is particularly true in the marine and climate

[11] Ibid, p35

domain. Over the past five years or so, significant institutes, centres, and collaborative programs, often involving collocation, have been established in Hobart, Sydney, Brisbane, Townsville, Darwin, Perth, Adelaide, and Melbourne – see diagram below.



IMOS is well-engaged with all of these initiatives, adding considerable strength to the national partnership model, and providing additional incentive to sustain it over the long term.

Current Facilities (and Operating Institutions) are listed below. The eleven Facilities are solely or jointly operated by nine different Institutions:

1. Argo Floats (CSIRO[12])
2. Ships of Opportunity (CSIRO, BOM, AIMS)
3. Deepwater Moorings (UTAS, CSIRO, BOM)
4. Ocean Gliders (UWA)
5. Autonomous Underwater Vehicles (SIMS)
6. National Mooring Network (CSIRO, AIMS, SIMS, SARDI, Curtin University)
7. Ocean Radar (JCU, SARDI)
8. Animal Tagging and Monitoring (SIMS)
9. Wireless Sensor Networks (AIMS)
10. Satellite Remote Sensing (CSIRO, BOM, UTAS, AIMS)
11. Information Infrastructure (UTAS)

[12] All acronyms not spelt out at first use, principally Institutional names, are explained in ATTACHMENT 1

The current Facilities and Sub-Facilities have a science rationale articulated through Node Science and Implementation Plans. The move to a National Plan with Node chapters (see previous section) is expected to assist in articulating the need to sustain, grow or decommission existing Facilities and Sub-Facilities, and to identify areas where new platforms, sensors and data streams need to be brought into commission.

The IMOS community identified some potential new areas through the EIF Planning Process. Proposals which could not be afforded under EIF but were assessed as 'desirable' or potentially suited for 'next stage' investment included macro nutrients, marine microbes, tropical fluxes, surface drifters, and fastened sea ice (fast ice). IMOS is also supporting national working groups (e.g. in bio-optics) and national workshops (e.g. on national coastal observing, greater synergy between observations and models, and sustained ecological observing) in order to develop community consensus on forward directions in these areas. Guided by the Strategic Roadmap for National Research Infrastructure, and informed by these marine and climate community deliberations, it is expected that IMOS will enter the next phase with a widely-supported plan for future investment in integrated marine observing.

IMOS will continue to build institutional strengths into national capability by:

a) Effective governance of the Lead Institution/Operating Institution model, assisted by the Advisory Board, and operating as a national partnership.

b) Effective management of Facility Operator performance through contractual milestones and Annual Business Planning, with a clear focus on availability of data streams in usable formats, and a partnership perspective that acknowledges the considerable co-investment being provided by Operating Institutions.

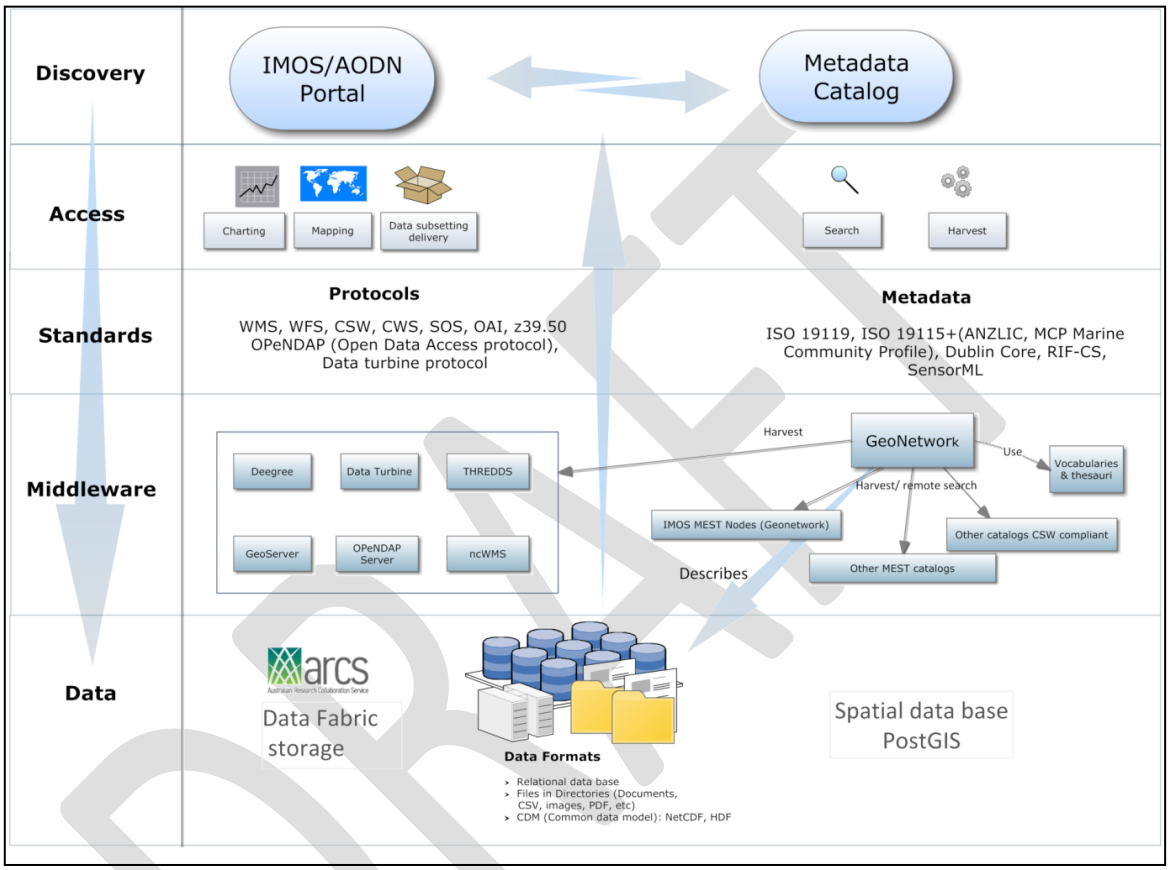
c) Continuous evaluation of the utility of data streams so as to maximise science return on investment for the marine and climate community.

d) Strong engagement with growing multi-institutional partnerships in the marine and climate domain.

e) Development of community consensus on the need to sustain, grow, commission, or decommission particular Facilities and Sub-Facilities, through National and Node Science and Implementation Planning, supplemented by targeted working groups and workshops, and underpinned by openness and transparency in decision making.

4. In the context of Australia's e-Research agenda, leveraging IMOS electronic marine information infrastructure to help create a culture that enables all Australian marine and ocean climate data to be discoverable, accessible, and interoperable

A key element of IMOS is the electronic Marine Information Infrastructure (eMII) Facility, which is also operated by UTAS as the Lead Institution. eMII is responsible for creating and developing the information infrastructure required to make all IMOS data discoverable and accessible through open access. The components of this infrastructure are illustrated in the following diagram:



eMII successfully launched the IMOS Ocean Portal in June 2009, and availability of data and functionality of the infrastructure has continued to improve since that date. eMII is now placing increased emphasis on adding value to IMOS data streams through development of data products, development of data exploration capability, enabling interoperability of different types of data, and ensuring data is 'model-ready'.

This infrastructure does not need to be limited to IMOS data streams, and is technically capable of serving all Australian marine and ocean climate research data. Since 2005, the six Australian Government Agencies with significant marine and ocean climate data holdings (AIMS, AAD, BOM, CSIRO, GA and RAN) have been committed to a vision of creating an Australian Ocean Data Network (AODN) - Australia's 'digital ocean commons'. With some additional funding from DIISR, IMOS has taken responsibility for establishing an AODN Development Office (DO) to make this vision a reality.

eMII and AODN DO are being merged into a single Facility that will work with the national marine data management community to develop a single, AODN information infrastructure. This infrastructure will enable discovery of and access to data managed centrally through IMOS, and

through distributed hosting by committed Australian Government agencies and other parties. There is strong and growing interest from Universities, State Government Departments, and Industry partners to participate in this national endeavour and many are already 'buying in' to the AODN, either though developing their own capability to host or by providing their data to interested AODN partners. It is expected that, over time, all relevant Australian Government funded research programs, and some if not all State Government funded research programs, will mandate that the data collected with their funding becomes discoverable and accessible through AODN.

The IMOS information infrastructure has been created within a broader Australian e-Research context. It utilises the distributed data storage and access methods currently supported by the Australian Research Collaboration Service (ARCS), and will engage with the new Research Data Storage Infrastructure (RDSI). IMOS (in conjunction with TERN, the Terrestrial Ecosystem Research Network) is now working with the National Computational Infrastructure (NCI) in the area of satellite remote sensing data and products. IMOS is also looking to participate in the new National e-Research Collaboration and Tools (NeCTAR) program (covering national servers, e-research tools, virtual laboratories, and research cloud). All of this national information infrastructure is underpinned by Australia's Academic and Research Network (AARNET) fibre optic backbone, noting that restricted bandwidth across Bass Strait has for some time been an inhibiting factor that we hope will soon be removed.

IMOS is working with the Australian National Data Service (ANDS) to support development of the Australian Research Data Commons and collaborating with other NCRIS capabilities, specifically TERN, Atlas of Living Australia (ALA) and AuScope, to share infrastructure where appropriate and explore opportunities for establishing a generic information infrastructure that has potential to contribute strongly to the Australian Government's National Plan for Environmental Information (NPEI).

Within the marine and climate domain, international collaboration is fundamentally important and this is no less true in the area of information infrastructure. IMOS has strong and growing links with comparable programs in the US (US-IOOS) and Europe (EuroGOOS), and will both benefit from and contribute to global marine and ocean climate data management initiatives.

IMOS will continue to develop its national-scale electronic marine information infrastructure by:

a) Ongoing investment in a dedicated information Facility, located with the IMOS Office, to provide the central component of a national 'hub and spoke' approach to marine data management.

b) Hardening the current system to improve performance and reliability.

c) Working with the IMOS community to indentify priorities for adding value to data streams - through development of data products, development of data exploration capability, enabling interoperability of different types of data, and ensuring data is 'model-ready'

d) Working with committed partners to implement the vision of an Australian Ocean Data Network (AODN), as Australia's 'digital ocean commons'.

e) Engaging with the national e-Research agenda, and collaborating with other NCRIS capabilities to share infrastructure and contribute to the National Plan for Environmental Information.

f) Partnering with comparable international programs to ensure Australia both benefits from and contributes to global marine and ocean climate data management initiatives.

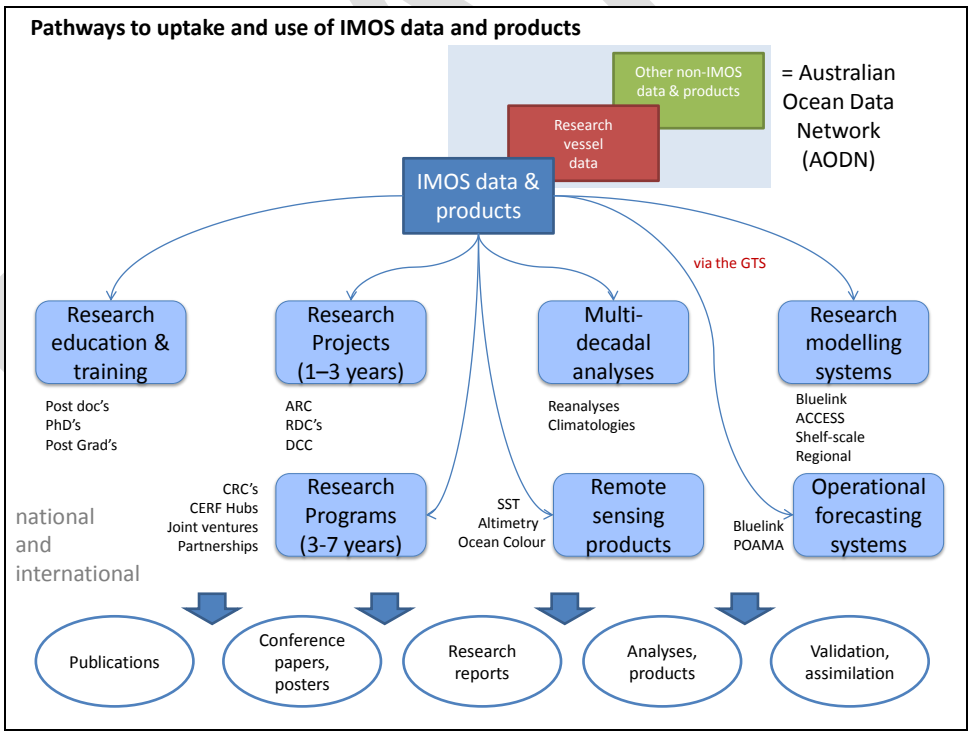
5. Ensuring IMOS data is taken up and used for marine and climate research that addresses national priorities in order to benefit Australian society, by implementing a comprehensive plan of engagement with all relevant components of the National Innovation System

The goal of IMOS is to provide ocean observations required by the marine and climate science community to undertake research of national significance relevant to:

- Climate change
- Climate variability and weather extremes
- Management of the marine environment
- Management of fisheries & aquaculture
- Development of offshore resources
- Planning and management of coastal and offshore infrastructure
- Maritime Defence
- Marine emergency management, and
- Science and Education.

It is also recognised in the NCRIS Evaluation Report that research infrastructure may have complementary functions for other purposes, such as supporting operational uses and applications[13].

IMOS has established multiple pathways to uptake and use, as illustrated below:



Performance indicators on use of IMOS data in research projects, PhD's, published papers, and conference papers are reported on an annual basis, and the numbers are building impressively. This is a complex area, and IMOS is devoting some effort into developing more sophisticated and efficient systems for gathering this performance information. There is also national and global interest in finding better ways to track use of data in an era of open access (e.g. via digital object identifiers).

[13] Ibid, p4

Potential users of IMOS data include all providers of Australian marine and climate science i.e.

- Universities, with a focus on education and training as well as strategic research
- Australian Government Agencies, both Research Agencies (AIMS, CSIRO) and Operational Agencies with significant research capacity (BOM, AAD, GA, ABARES, DSTO)
- State Government Departments with responsibility for environment and natural resources, fisheries/primary industry/economic development, climate change, and
- Private industry, with a focus on commercial application.

As IMOS has matured and the basis for engagement with stakeholders has broadened and deepened, it has become clear that it will not be sufficient to just engage the providers of marine and climate science in design and development of the observing system. Users of this science are increasingly seeing themselves as key stakeholders, including Australian Government Departments (e.g. in Climate Change, Environment, Fisheries), State Government Departments, Industries and the Community. Approximately 20% of the co-investment required to operate IMOS at its current scale comes from Australian Government programs, and a further 15% from State Governments.

This is a very positive development in terms of long-term sustainability, but the engagement will need to be well-managed to ensure the needs of both institutional providers (the core partners and major co-investors in IMOS), and users of the science, are met. Risks include tension between the priorities of providers and users, and pressure to redirect the sustained observing system to meet shorter-term, more tactical needs.

IMOS will manage this important development through a comprehensive strategy for engaging with the various partners in the Australian national innovation system. The context for Australian marine and climate science is set by the National Research Priorities, which will inform the Strategic Roadmap for Australian Research Infrastructure and give rise to major programs such as the Marine and Climate Super Science Initiative. High level planning within IMOS will then be set by the relevant national science frameworks, such as the National Framework for Marine Research and Innovation being led by the Oceans Policy Science Advisory Group (OPSAG)[14], and the National Climate Change Science Framework[15]. More detailed planning (e.g. at Node level) will then be informed by long-term research programs at national and regional levels, and the long-term strategies of institutional partners.

IMOS will seek to ensure that its data is taken up and used for the benefit of society by:

a) Establishing multiple pathways to uptake and use across the various dimensions of Australian marine and climate science

b) Measuring and reporting performance through increasingly sophisticated methods to track the use of IMOS data, and demonstrate the value of investing in a national, integrated system.

c) Implementing a comprehensive strategy for engaging across the Australian national innovation system to ensure that IMOS National and Node-level planning guiding development of the sustained observing system is fully informed by the long-term needs of both providers and users of marine and climate science.

[14] http://www.opsag.org/
[15] http://www.climatechange.gov.au/publications/science/cc-science-framework.aspx

6. Catalysing a national scale engagement between the marine observing system and marine modelling communities, to help improve the relevance and applicability of both

Since inception, IMOS data has been used to validate and develop models of marine systems and processes, and in some cases been directly assimilated into modelling, forecasting, and reanalysis systems. However it is clear that there is considerable potential to strengthen this relationship for the benefit of both the modelling frameworks and the observing system. This emerged as a very consistent theme in feedback received from international reviewers of IMOS Node Plans.

To the extent that Australia has national approaches to ocean and marine modelling, this engagement is quite straightforward e.g. with the Australian Community Climate and Earth System Simulator (ACCESS), and the Bluelink Ocean Forecasting System.

However much of the ocean and marine modelling in Australia is carried out at regional, institutional, group, and individual levels. It includes:

- Hydrodynamic modelling
- Biogeochemical/Trophodynamic modelling, and
- Ecosystem modelling.

There is potential for IMOS as the national-scale observing system to act as a catalyst for national-scale engagement with marine modelling communities, as appropriate. Prospective areas include coastal modelling and ecosystem modelling.

Within the broader national e-Research agenda, there is also potential for IMOS to bring its sensors, observations, and information infrastructure together with the modelling and visualisation communities into a 'virtual laboratory' environment, in which to explore the science questions around seamless integration of these components.

Interest is also emerging in observing system evaluation, where numerical models are used to help identify observational gaps and to improve the efficiency and effectiveness of the observing system for constraining ocean models. A small project has been commenced with CSIRO in this area.

IMOS will seek to take its engagement with the marine modelling communities to a higher level by:

a) Developing a clear plan to enhance the scientific application and uptake of IMOS data by marine modelling communities, including feedback to eMII on suitability of data products for use in models (access, formats), and provision of high-quality model output to the IMOS community.

b) Catalysing a national scale engagement in targeted areas such as coastal modelling and ecosystem modelling, through national workshops and other mechanisms.

c) Working with partners to quantitatively assess the efficiency and effectiveness of observing system design through application of model-based methods.

7. Engaging with terrestrial, freshwater, geological, cryospheric, and atmospheric research communities to promote systems-based research, particularly in the coastal zone

The marine and ocean climate science domain is highly multi-disciplinary, and IMOS is striving to establish and maintain an appropriately broad base - from bluewater to coastal, physical to ecological. However this domain still represents only one slice through the whole Earth system, and we must not lose sight of the fact that marine and ocean climate science fits into a much bigger picture. The Australian Academy of Science recently released '*An Australian Plan to Develop a Science of the Whole Earth System*'[16], though this thinking is at a very early stage. A science of the Earth system represents a huge global challenge.

For now it would seem sensible to undertake multi-disciplinary, domain-specific observations with 'open interfaces' and 'porous boundaries', so as to maximise the potential for increasingly complex systems-based research to evolve as Australian scientists and their international collaborators develop the capability to address these challenges, and as governments, industries and communities develop the capability to apply more sophisticated scientific knowledge.

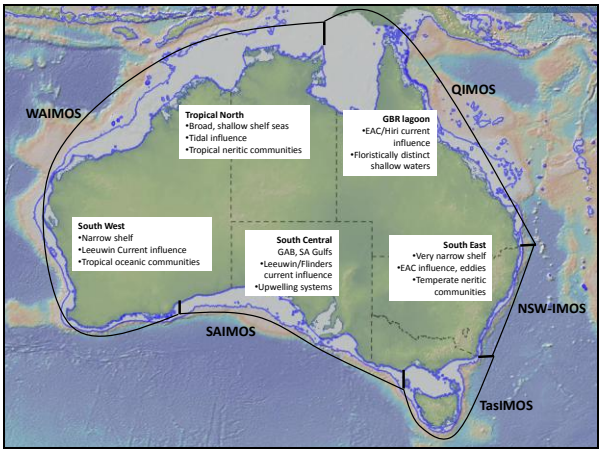
In the open-ocean, IMOS is quite well-positioned in this respect. Although there are very significant gaps in spatial coverage which we hope to close over time, the physical, chemical and biological oceanographers, atmospheric scientists, and marine biologists are all actively engaged. One significant disciplinary gap is the cryospheric community, and IMOS will look for opportunities to extend into the sea ice.

Moving across the continental shelf and into the coastal zone, the requirements morph from huge-spatial and (relatively) low-temporal, to fine-spatial and high-temporal. In addition:

- the marine systems become more complex, with seabed, terrestrial, and freshwater influences coming into play,
- the research provider space becomes more complex, with more scientists studying more variables at finer scales, and
- the science user space becomes more complex, with multiple State Government interests interacting with Australian Government interests, multiple Local Government interests, and more and more community and industry interests.

Widely-supported, national-scale, integrated, observing therefore becomes harder and harder to deliver. However the potential benefits of achieving it are commensurately high.

From a 'marine coastal' perspective, IMOS has dealt with this challenge by developing a series of regional coastal nodes, linked by a national backbone. With some strategically-placed EIF investments in northwest WA, southeast Queensland, and Tasmania, IMOS now has a Node structure covering Australia's coastal oceans, again noting that there are very significant gaps in spatial coverage which we hope to close over time – see opposite.



[16] http://www.science.org.au/natcoms/nc-ess/documents/ess-report2010.pdf

NCRIS also funded TERN, ALA, AuScope, and ANDS, all with interests in the coastal zone. While these capabilities were established within a national research infrastructure context, they were not established as an integrated package to address broader Earth system questions, for example in the coastal zone. And they are all at different stages of evolution. Opportunities to further integrate these capabilities to support more complex systems-based research should therefore be seen as emergent properties of a national approach to research infrastructure development, rather than remediation of previous fragmentation. The effort that will be required to further integrate across already highly multi-disciplinary domains should not be under-estimated.

TERN has begun reaching into the coastal zone with the establishment of an Australian Coastal Ecosystems Facility, albeit at small scale initially. IMOS and TERN will seek to strengthen their collaboration in the coastal zone at national, regional, and functional levels. At the functional level, there are obvious synergies in information infrastructure and remote sensing that are already being exploited. At the regional level, IMOS regional coastal Nodes and TERN supersites may offer opportunities for integration, again noting that they have not to date been designed with this end in mind. At the national level, it is harder to identify an obvious focus for the reasons outlined above. Coastal inundation, coastal water quality and marine spatial planning in coastal waters are issues of significance in Australia that may benefit from a more national approach to research infrastructure development if there is multi-jurisdictional will to achieve it. National scale engagement between the observing systems and modelling communities may also offer opportunities (see previous section).

In addition, the Australian Government has invested very significantly in water information through BOM, and CSIRO. Water observation and monitoring is highly relevant to integration in the coastal zone, across the atmospheric, terrestrial and marine domains, and it will be necessary to think 'beyond NCRIS' in this area. The National Plan for Environment Information is likely to provide an appropriate context for this broader consideration.

IMOS will seek to promote systems-based research by:

a) Continuing to support multi-disciplinary approaches in the marine and climate domain.

b) Engaging with the cryospheric community in the sea ice zone.

c) Continuing to strengthen the IMOS national backbone and extend the spatial coverage of regional coastal Nodes in Australia's coastal oceans.

d) Partnering with TERN and other capabilities to support more complex systems-based research in the coastal zone, at national, regional and functional levels.

e) Engaging with the National Plan for Environmental Information as it is developed.

8. Engaging with international ocean observing programs in our region, to ensure that Australia takes full advantage of collaborative opportunities in the Southern Hemisphere

Ocean observing is a global enterprise, and IMOS operates within an international context. This is particularly important for Australia, with its huge ocean territory and relatively small population.

As noted in the 2008 review of the National Innovation System, Australia's share of new knowledge and innovation each year is approximately 2% and "The quality of the 2 percent that we produce and its usefulness to the rest of the world will be important determinants in our ability to access the other 98 percent."[17] By making strategic investments in globally significant ocean research infrastructure, Australia attracts strong international collaboration on issues of national significance, and positions Australian marine and climate science to be world class. In this respect, our location in the southern hemisphere provides Australian marine and climate science with a natural advantage that can be exploited.

The global ocean observing world is extremely complex. The dimensions which are of significance to IMOS include:

- intergovernmental programs,
- inter-institutional programs,
- comparable national systems,
- international projects, and
- bi-lateral arrangements.

The Global Ocean Observing System (GOOS) is the principal intergovernmental mechanism in this domain. IMOS is increasingly being seen as Australia's GOOS 'regional alliance', and is well-engaged with the regional alliance in the Indian Ocean (IOGOOS). There may be potential to strengthen engagement in other areas, such as the Pacific. The Group on Earth Observations (GEO) is another relevant intergovernmental mechanism. It has traditionally come from a remote sensing (rather than in-situ observing) perspective, though seems to be showing increasing interest in ocean issues.

The International Council for Science (ICSU) sponsors inter-institutional programs through mechanisms such as its Scientific Committees on Oceanic Research (SCOR) and Antarctic Research (SCAR). These committees have jointly sponsored the planning for a Southern Ocean Observing System (SOOS), and UTAS is funding a position to establish the international project office in Hobart. This position will be collocated with the IMOS Office, and IMOS will be strongly engaged with Australia's contribution to SOOS.

Australia's approach to integrated marine observing is attracting international attention, and fostering collaborations with comparable systems in other countries/regions, including the United States (US-IOOS) and Europe (EuroGOOS). Information infrastructure is emerging as an area in which there is particularly strong interest in collaboration.

Most IMOS Facilities have some international connection, to the extent that some are in fact local components of fully-integrated global networks (e.g. Argo). IMOS will continue to ensure its Facilities are embedded in relevant international projects to the full extent possible.

[17] Venturous Australia, p20 http://www.innovation.gov.au/Innovation/Policy/Documents/NISReport.pdf

The Australian Government enters into bilateral scientific arrangements with other countries/regions. Recent engagements with the US, Europe, China and New Zealand have all included some focus on ocean observing. In addition, particular Institutions (such as AIMS and CSIRO) have bi-lateral arrangements with relevant institutions in other countries (such at the National Oceanic and Atmospheric Administration, or NOAA, in the US), providing further opportunities for international partnership.

IMOS will take full advantage of international collaboration opportunities in the Southern Hemisphere by:

a) Continuing to engage with the relevant intergovernmental and inter-institutional programs.

b) Collaborating with comparable systems in other countries/regions, with a particular emphasis on information infrastructure.

c) Continuing to ensure that IMOS Facilities are embedded in relevant international projects to the full extent possible.

d) Leveraging bi-lateral arrangements to strengthen partnerships in line with national and institutional priorities.

9. Improving efficiency through vigorous collaboration, data capture and reuse, and ongoing technical innovation

The cost of sustained ocean observing is not trivial, and demand from the marine and climate science community will always exceed our ability to provide observational data streams. IMOS needs to maintain a focus on improving efficiency through multiple mechanisms, to ensure that the substantial investments being made continue to deliver maximum scientific return, and have as much utility as possible.

Vigorous collaboration within the IMOS community will be fundamental. Moving to a National Science and Implementation Plan will enable better integration of open-ocean and coastal components, a more effective and efficient national backbone, and less risk of fragmentation across coastal regions. Continued development of IMOS Facilities as broadly-based platforms addressing multiple science questions will also drive efficiency.

A primary focus for IMOS will continue to be on data capture and reuse. This will cover not only IMOS-funded data collection, but also on other Australian marine and ocean climate data to be made available through the AODN. Particular emphasis will be placed in the coastal zone, where there is much potential for a national scale information infrastructure to assist in overcoming historical fragmentation.

Technical innovation will also be crucial, both in driving down the cost per observation over time, and in establishing transformational approaches to complex problems.

As a sustained observing system, IMOS will not be on the 'bleeding edge' of ocean technology development. However by continuously reviewing the maturity profile of new technologies and approaches, and by partnering with the Institutions trialling them in experimental contexts, significant progress should be achievable over time. Profiling moorings and wave gliders are two examples of technologies currently 'under watch'.

In terms of transformational approaches, particular emphasis will be placed in the area of sustained ecological observing. While current investments in trophic-level observing are necessary to take our knowledge of marine ecosystems to the next level, a 'bottom-up, top-down' approach is unlikely to yield the level of systems understanding ultimately required. The potential of 'omics' and other capabilities to transform our capacity to observe the functioning of marine ecosystems will need to be carefully evaluated. The recently-completed, global Census of Marine Life had a major focus in this area, and IMOS will engage with national and international efforts to take this forward.

IMOS will strive to improve its efficiency by:

a) Continuing to pursue vigorous collaboration within the IMOS community, across Nodes and Facilities.

b) Continuing to focus on data capture and reuse, of both IMOS-funded data collection, and other Australian marine and ocean climate data to be made available through the AODN.

c) Continuing to review new innovations in ocean observing technology with a view to shifting the IMOS Facility portfolio over time, to both lower cost per observation and to seek transformational approaches to complex problems.

10. Engaging with operational agencies and other partners responsible for delivering marine environmental information and ocean products and services, to ensure that IMOS co-evolves with related operational observing systems

IMOS has been established as a research infrastructure program, to deliver ocean observations to the marine and climate science community so that they can undertake research of national significance. It is not an operational system. However the broader utility of research infrastructure investments has been recognised in the recent NCRIS Evaluation Report (see section 5).

BOM is the main Australian Government agency providing marine and oceanographic services to the Australian community – marine weather warnings, forecasts of winds and waves, tide predictions, forecasts of sea surface temperature (SST) and currents, and tsunami warnings (see http://www.bom.gov.au/marine/index.shtml). This is in addition to the BOM's responsibilities for weather forecasting (including extreme weather) and provision of climate information (including seasonal prediction) that also rely on ocean observations. BOM draws on its own observational systems, as well as IMOS and other data that goes onto the Global Time Series (GTS) e.g. from the global Argo program. IMOS and BOM are therefore in close collaboration to ensure that synergies between the research and operational systems are maximised.

This relationship will increase in importance in the near future as the BOM is in the process of being given much greater responsibility for environmental information in Australia, including information on marine ecosystems and ocean resources. Under the National Plan for Environmental Information (NPEI), BOM and the Environment Department will work together during 2010-14 to develop a framework for producing national environmental accounts, and (eventually) national environmental outlooks.

A number of Australian Government agencies other than BOM currently have operational responsibilities that rely on ocean observations, such as the Australian Maritime Safety Authority, the Royal Australian Navy, Australian Fisheries Management Authority, and Great Barrier Reef Marine Park Authority. Various State and Territory Government departments undertake regular monitoring programs in order to manage their responsibilities in coastal waters. Large marine industries such as offshore oil and gas also make significant investments in ocean observing in order to manage and grow their operations.

A key element of IMOS strategy is to lead the development of a national marine information infrastructure (AODN) that will enable IMOS data and other Australian research and operational ocean data to become discoverable, accessible and interoperable for the benefit of the nation as a whole. In this way, valid differences between research and operational needs can be respected, and synergies between research and operational systems can be fully-exploited, over time.

IMOS will ensure that it co-evolves with related operational observing systems by:

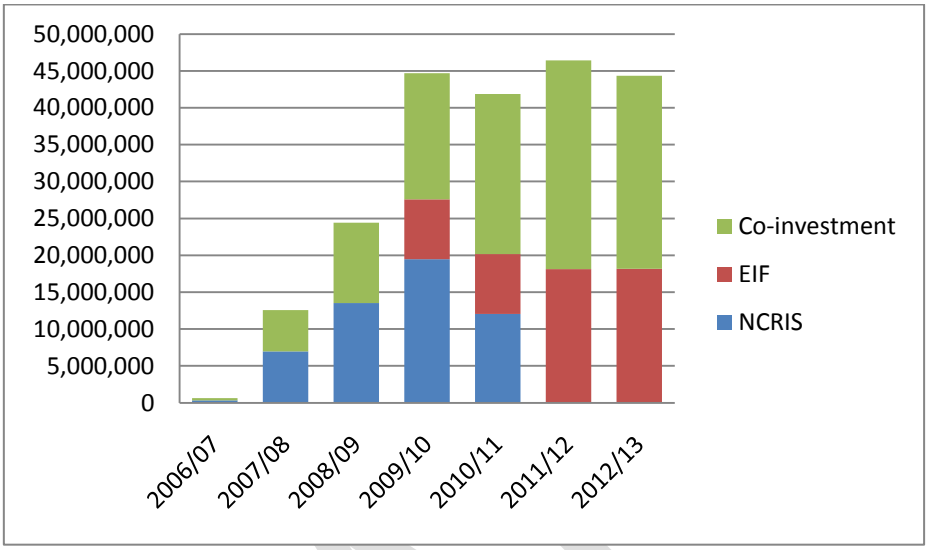
a) Making IMOS data streams as broadly useful as possible.

b) Collaborating closely with BOM, and other agencies as appropriate, including in the development of the National Plan for Environmental information.

c) Continuing to focus on making IMOS-funded data and other Australian marine and ocean climate data available through the AODN.

Forward Planning Scenarios

One of the challenges in establishing IMOS has been to scale the system to a level which can be sustained based on total available resources. The funding profile shown below indicates that we have been quite successful in achieving this, with total resources levelling out at ~$45M per annum since 2009-10. In 2012-13, core funding will be $18M and projected co-investment ~$26M.



This gives a good indication as to what it would take to maintain and sustain the system as currently implemented.

There are clearly opportunities to grow IMOS if further funding is available. Both the NCRIS and EIF funding processes were heavily over-subscribed based on proposals received from the IMOS community. The EIF process was managed in such a way that unsuccessful proposals were assessed as 'highly desirable', suitable for 'next stage' investment, or unsuitable for IMOS investment. Furthermore, Node Science and Implementation Plans have been written with an eye to the longer term, and they identify a number of important gaps.

Whilst further consultation with the marine and climate science community is required, particularly in response to the Strategic Roadmap for Australian Research Infrastructure, IMOS has sufficient information to consider at least two forward planning scenarios beyond 'maintain and sustain':

1. Evolutionary growth, to fill identified gaps, and
2. Strategic enhancement, to move into new areas of national priority.

1. Evolutionary growth

In the bluewater, major gaps remain in the deep ocean, the high latitudes, and the tropics. IMOS has commenced the monitoring of Antarctic Bottom Water formation off the Antarctic Coast. However plans to track the fate of bottom water by monitoring the Kerguelen Abyssal Boundary Current and the Perth Basin Abyssal choke point are yet to be implemented. In the tropics, measurement of relatively rapid intraseasonal variability in ocean/atmosphere fluxes is a high priority for improving seasonal climate prediction. Plans to deploy a flux mooring as part of the international Tropical Moored Buoy array are yet to be implemented.

IMOS has begun to make good progress in monitoring major boundary currents and inter-basin flows with recent investments in the Indonesian Throughflow and East Australian Current (off

Brisbane). However plans to monitor full depth transport of the Leeuwin Current off Perth, and the Tasman Outflow at the South Tasman Rise, are yet to be implemented.

Significant gaps remain in our coverage of Australia's coastal oceans. This is particularly true across Northern Australia. To date we have only made a modest start between the Kimberley and Bonaparte Gulf, and have no infrastructure in the Arafura Sea, Gulf of Carpentaria or Torres Strait. In South Eastern Australia, strategically important gaps remain in Stockton Bight (NSW), the Bonney and Otway Coasts (SA/Victoria), and the west coast of Tasmania.

2. Strategic enhancement

Three potential areas of strategic enhancement have emerged to date – in sea ice, in national coastal observing, and in sustained ecological observing.

While IMOS has begun to invest in the high latitudes (above 60^0S), through ice-capable Argo and sensors on seals, we do not currently have any engagement with the cryospheric community in monitoring sea ice. A proposal for fastened sea ice (fast ice) monitoring was made under EIF and assessed as 'highly desirable', but was not able to be funded. There is also growing interest in developing under-ice capability e.g. though an autonomous underwater vehicle. Developing sea ice capability would make IMOS a more credible partner in the new Southern Ocean Observing System.

IMOS has a substantial footprint in the coastal zone, but the 'sum of the parts', articulated through our regional coastal nodes, does not yet add up to a satisfying 'whole' for many in the coastal research community. Interest has been growing in the development of a more national approach to coastal observing, and a number of meetings and workshops have been held on this general topic. As noted in other parts of this strategy document, the coastal zone is a shared space, and IMOS is but one player. However our community does have more to offer in this important area, and the IMOS regional coastal Node structure (now supported by a National Science and Implementation Plan) provides a solid basis on which to build with partners such as TERN. In addition, the GOOS Panel for Integrated Coastal Observation (PICO) is about to publish a Requirements-Based Phased Action Plan identifying several 'High Priority Phenomena of Interest' for which 'End –to-End Solutions' could be developed through a integrated coastal observing and modeling system. Of the various issues covered by this framework, coastal inundation, coastal water quality and marine spatial planning in coastal waters are certainly issues of significance in Australia, and the wisdom of the global ocean observing community may be helpful in this context.

IMOS is striving to be a truly biophysical observing system, addressing science questions about ecosystem responses as well as physical processes. However observing natural and anthropogenic change is more difficult for biology than it is for the physics or chemistry, and it is more difficult for some trophic levels than others. And measuring all trophic levels at the same time over large areas is not considered feasible. A 'bottom-up, top-down' approach, while necessary to improve our current understanding, is unlikely to yield the level of systems understanding required in the long term. Stronger engagement with the ecosystem modelling community will be part of the solution. However there would also seem to be potential for transformational approaches in the area of sustained ecological observing.

In closing, it should be noted that these forward planning scenarios are not mutually exclusive, and hybrid approaches could be readily developed.

ATTACHMENT 1 – Acronyms not spelt out at first use (principally Institutional names)

Acronym	Full Title
AAD	Australian Antarctic Division
ABARES	Australian Bureau of Agricultural Resource Economics and Sciences
ACECRC	Antarctic Climate and Ecosystems Collaborative Research Centre
AIMS	Australian Institute of Marine Science
ANU	Australian National University
ATRF	Arafura Timor Research Facility
BoM	Bureau of Meteorology
CAWCR	Centre for Australian Weather and Climate Research
CDU	Charles Darwin University
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUT	Curtin University of Technology
DECCW	Department of Environment, Climate Change and Water (NSW)
DEEDI	Department of Employment Economic Development and Innovation (QLD)
DERM	Department of Environment and Resource Management (QLD)
DSTO	Department of Defence (Defence Science and Technology Organisation)
ECU	Edith Cowen University
ESA	European Space Agency
GA	Geoscience Australia
I&I NSW	Industry & Investment NSW
IMAS	Institute of Marine and Antarctic Studies
IOMRC	Indian Ocean Marine Research Centre
JCU	James Cook University
MAFFRI	Marine and Freshwater Fisheries Research Institute
MHL	Manly Hydraulics Laboratory (NSW)
MISA	Marine Innovation SA
NASA	National Aeronautics and Space Administration
PIRSA	Department of Primary Industries and Resources of South Australia
RAN	Royal Australian Navy (Directorate of Oceanography and Meteorology)
SA DNR	South Australia Department of Environment and Natural Resources
SARDI	South Australian Research and Development Institute
SIMS	Sydney Institute of Marine Science
TAFI	Tasmanian Aquaculture and Fisheries Institute
TMN	Tropical Marine Network
UNSW	University of New South Wales
UQ	University of Queensland
USyd	University of Sydney
UTAS	University of Tasmania
UTS	University of Technology Sydney
UWA	University of Western Australia
Vic EPA	Victoria Environmental Protection Agency
WA DEC	Western Australia Department Environment & Conservation
WA DoT	Western Australia Department of Transport
WA Fish	Western Australia Department of Fisheries
WAMSI	Western Australia Marine Science Institute

IMOS Integrated Marine Observing System

University of Tasmania
Private Bag 110
Hobart Tasmania 7001
http://www.imos.org.au